A RAND NOTE

AN INTRODUCTION TO NINJA

J. R. Clark, T. G. Covington, W. J. Whelan

October 1984

N-2222-ARPA/RC

Prepared for The Defense Advanced Research Projects Agency

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PREFACE

This Note documents the final briefing of the Defense Advanced Research Projects Agency/Tactical Technology Office (DARPA/TTO)-sponsored study, "Robotic Weapon Systems." This study was begun in August 1983 and substantially completed approximately a year later; in addition to DARPA sponsorship, it was also partly supported through Rand's own funds. The study aimed to develop new robotic weapon systems concepts for possible subsequent development as elements of a future DARPA/TTO Tactical Robotics Program. From among the various robotic weapon concepts considered, the topic of this Note--the Ninja light ground combat vehicle--emerged, in the judgment both of Rand and of the DARPA sponsors, as the most promising centerpiece for the planned robotics program.

The briefing on which this Note is based was presented to a wide variety of audiences within DARPA and the Military Services and generated substantial interest. Because the Note suggests possible directions in advanced combat vehicle system technology, it should be of interest to DARPA and Service program managers and others concerned with artificial-intelligence/robotics and battlefield weapon systems.

SUMMARY

Ninja is a major new combat vehicle concept. It is an advanced, light, hard-hitting, survivable fighting system that takes a new approach to achieving improved battlefield capabilities: man-aided artificial-intelligence/robotics. This novel, and as yet untested, technology promises to dramatically reduce vehicle size without proportionately reducing combat effectiveness. This reduction is made possible by shifting many tasks, which have traditionally required several human crew members, to automated subsystems. The remaining tasks--largely supervisory/override/decision-oriented--are assumed by a single crew member.

The Ninja concept offers the potential for dramatic improvements in the firepower, mobility, and survivability of light fighting vehicle systems. These improvements could bolster the effectiveness of U.S. Army light division forces, joint Army-Marine Corps rapid deployment forces, Marine amphibious forces, and U.S.-NATO armor forces.

Achieving the promise of Ninja entails several tasks:

1. Development of the Ninja system concept, including appropriate technology assessments, operational as well as technical concept definition, and detailed review of the supporting technologies.
2. Generation of Ninja system design criteria and technology development guidelines to provide the necessary direction and focus for initial Ninja R&D plans.
3. Preparation of a Ninja-related research program, specifying required technology development efforts.

Ninja represents a novel and generic approach for future combat vehicle systems and offers the opportunity to apply the accomplishments of previous and ongoing successful DARPA programs in advanced sensor, weapon, and fire control technologies. The Ninja research program will complement other DARPA activities, including the Autonomous Land Vehicle

and Electromagnetic Launch programs. Current Service interest in the Ninja concept indicates a strong potential for joint DARPA-Service research.

ACKNOWLEDGMENTS

The authors acknowledge their Rand colleagues: Richard Salter, for his constructive and timely review of this Note, and Rick Eden, for his assistance in translating the briefing on which this Note is based to the printed page.

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I. INTRODUCTION

Over the past several years Rand has been actively involved in efforts to improve military combat vehicle capabilities and methods of employment.[1] The focus of this activity has moved increasingly toward concepts for incorporating modern computational technologies and techniques--e.g., robotics and artificial intelligence--in combat systems. This Note describes a new, highly automated, light ground combat vehicle system concept--Ninja--that was developed for the Defense Advanced Research Projects Agency/Tactical Technology Office (DARPA/TTO), and is the cornerstone of TTO's planned Tactical Robotics Research Program.

Ninja is a major new combat vehicle concept. It is an advanced, light, hard-hitting, survivable fighting system that takes a new approach to achieving improved battlefield capabilities: it applies AI/robotics technology and advanced target acquisition and engagement technologies to reduce crew and vehicle size dramatically while increasing battlefield effectiveness. This reduction is made possible by shifting many tasks, which have traditionally required several human crew members, to automated subsystems. The remaining tasks--largely supervisory/override/decision-oriented--are assumed by a single crew member.

The Ninja concept is distinguished by the following major features:

- One crew member rather than three or four;
- Man-aided AI/robotics station;
- Integrated multi-sensor suite for fire control and target acquisition;
- Integrated multi-weapon suite;
- Tactical and strategic transportability;
- High survivability, due to small size, high mobility and agility, and augmented armor protection.

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[1]See bibliography for a list of selected Rand references.

Although Ninja is a novel concept with many advanced aspects, it is designed to exploit previous and current DARPA research and development efforts, e.g., STARTLE, Tankbreaker, Advanced Combat Vehicle. The Ninja program also affords a versatile means to explore and develop selected robotic subsystem technologies which can be used in various future tactical weapons or weapon support systems. Technology development projects derived from the Ninja concept should be good candidates for joint DARPA-Service endeavors and should be able to use developing and existing research testbeds. For example, vehicle testbeds developed by the U.S. Army Robotic Reconnaissance Vehicle, DARPA/Defense Sciences Office Autonomous Vehicle, or the U.S. Marine Corps Autonomous Land Vehicle programs could be used to develop and demonstrate various Ninja subsystems.

Section II of this Note describes the performance goals of Ninja as they are currently conceived. Section III surveys the technological advancements required to make the Ninja concept a reality. Section IV proposes a schedule for the Ninja program, and the Appendix describes several other current concepts which resemble Ninja to some degree.

II. THE NINJA APPROACH

The Ninja concept can meet the need of the Army and Marine Corps for a combat vehicle system that is light, hard-hitting, and survivable.[1] By hard-hitting and survivable we mean a system that can face and defeat heavy armor units. By light we mean a system that can be deployed worldwide. Such a system would be suitable for light division, Rapid Deployment Joint Task Force (RDJTF), and contingency missions.

The intended applications of Ninja suggest the following performance goals:

- **Firepower**--Ninja should possess a day/night, all-weather capability to engage a wide tactical target array.
- **Transportability**--Ninja should be small and light enough to be transported by helicopter and intratheater air lift.
- **Survivability**--Ninja should present a small, agile, responsive, hard target.
- **Life Cycle Costs**--Ninja should reduce by at least half the number of personnel required for operation and maintenance at the combat vehicle level.

In this section we will consider each of these goals in more detail.

FIREPOWER

Table 1 displays the weapons suite that we are proposing for Ninja together with the tactical target array for which it is designed. Other suites which also adequately address the target array may also be considered, and each Ninja vehicle need not carry the same weapons suite. However, there are sound reasons for selecting this particular suite.

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[1]The Appendix compares Ninja to several other concepts which address similar needs.

Table 1

FIREPOWER

WEAPONS SUITE	TARGET ARRAY
Missile (Focal Plane Array)	Tanks, helicopters
Gun (40-50 mm)	Light armored vehicles, bunkers, urban structures, helicopters
Machine gun (7.62 mm)	Personnel
Grenade launcher	Personnel
Smoke generator	No fire option

Missile. The missile is present to defeat the toughest targets on the battlefield. These are primarily tanks, but the missile should also have some capability against helicopters. Most likely, the missile will be command-guided (aided by a mast-mounted sensor array); however, the nature of Ninja and its probable modes of employment suggest that a launch-and-leave missile may also be appropriate.

Gun. Because the missile is sufficient against tanks, we propose a relatively small gun; it could even be as small as 25 mm. Since one of Ninja's greatest assets is its small size, the gun should not be any larger than necessary to address its share of the target array. In any case, the Ninja platform will not support a very large gun.

Machine gun and grenade launcher. These are intended to provide regular anti-personnel capabilities.

Smoke generator. We propose that Ninja possess a very high capability to generate smoke, sufficient to hide the vehicle almost instantaneously. This capability, together with its small size and high agility, will permit Ninja to avoid engagements in which it would be at a disadvantage.

TRANSPORTABILITY

Considerations of both strategic and tactical transportability suggest that Ninja should weigh a maximum of 12 1/2 tons in transport configuration. Although this is a light system, it should be still lighter if possible, both to increase mobility and to afford additional armor or weapons if desired.

Table 2, which shows a range of combat and transport weights for typical vehicles, reveals how the capacities of three cargo planes constrain the possible transport weight of Ninja. At a transport weight of 12 1/2 tons, two Ninja systems would fit into a C130. This weight should probably include a certain amount of fuel and ammunition so that the system will have at least a limited fighting capability as soon as it is unloaded.

Figure 1 suggests the weight limits for tactical transportability by focusing on the capability of the Marine Corps' CH-53E helicopter. As payload increases, of course, the range decreases, but at some weight the range begins to fall dramatically. Using the Marine standard (the lower of the two curves shown), this point comes at about 12 1/2 tons. A practical, transportable Ninja might be expected to fall in the shaded

Table 2

STRATEGIC TRANSPORTABILITY

Combat Weight	Transport Weight	C130	C141B	C5A
13.5	11.5	2	$\boxed{3}$	10
14.5	12.5	$\boxed{2}$	2	9
16	14	1	2	8
$\boxed{21}$	$\boxed{19}$	1	$\boxed{1}$	6
22	20	1	0	$\boxed{6}$
27	24	1	0	$\boxed{5}$
28	25	1	0	4

$\boxed{}$ Vehicle weight constraint factor
C130 and C5A — payload weight
C141B — floor loading limit

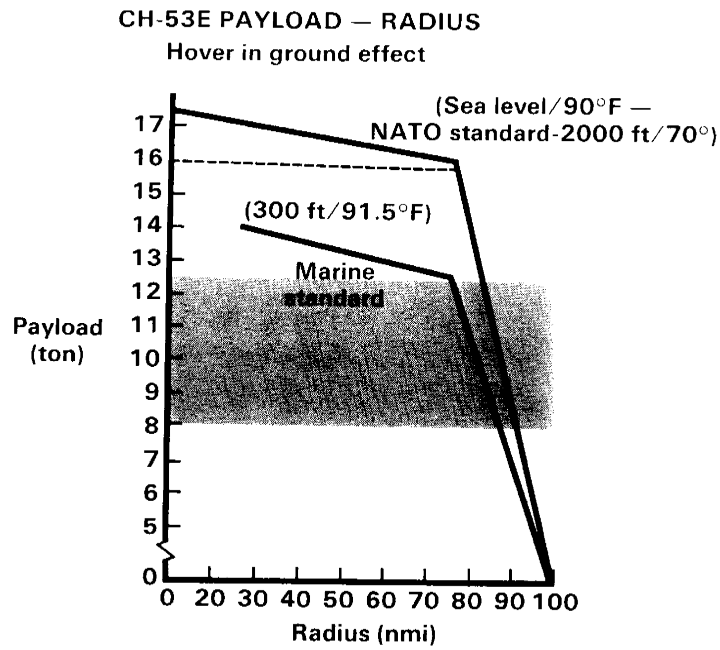

Fig. 1 -- Tactical transportability

band in the figure--probably toward the high side. We use the more rigorous Marine standard because we envision Ninja possibly being transported off ship decks, where helicopters cannot rely on the ground effect; the Marine standard excludes lift enhancement via ground effect. As of this writing, the U.S. Marine Corp's Light Armored Vehicle is specified to weigh 16 tons or less in transport--the dashed line in the figure.

A transport weight under 12 1/2 tons appears to be a realistic goal. Current design studies on the Mobile Protected Gun System suggest that a three-man system can weigh as little as 15+ tons. As a one-man system, Ninja will have a greatly reduced armored volume. We can expect to save approximately 1 1/2 to 2 tons per crew member. Some of these weight savings, of course, must be spent on additional machinery to perform missing crew members' functions. But we should still be able to design a system weighing little more than 11 tons, substantially less than the 12 1/2 ton upper limit. And with the difference we can explore ways to increase Ninja's firepower and survivability.

SURVIVABILITY

Ninja should present a hard, small, agile target.

The hardness of the system is constrained by weight considerations. But if we can design a system substantially below the maximum transport weight, we can investigate the use of applique or system integrated armor.

The small size should increase survivability by making the system difficult to target. Figure 2 shows the Ninja system in silhouette against a typical main battle tank. Figure 3 suggests how the two systems will differ when viewed through the gunner's optics. The Ninja will be much more difficult to sight.

The mobility of Ninja will also contribute to its survivability. We envision a system capable of accelerating from halt position and travelling 200 m in 17 seconds or less. It is generally agreed that a well-designed tracked vehicle requires on the order of 20 to 22 horsepower per ton at the sprocket to achieve this performance. We chose this goal because earlier studies suggest that in many terrain

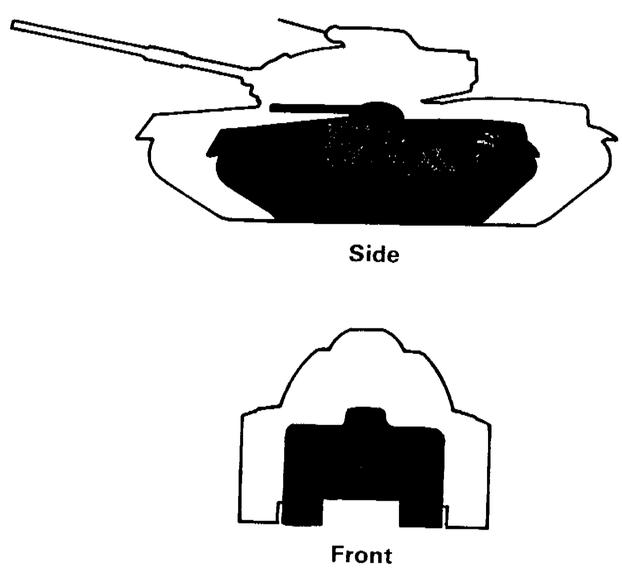

Fig. 2 -- Comparative size

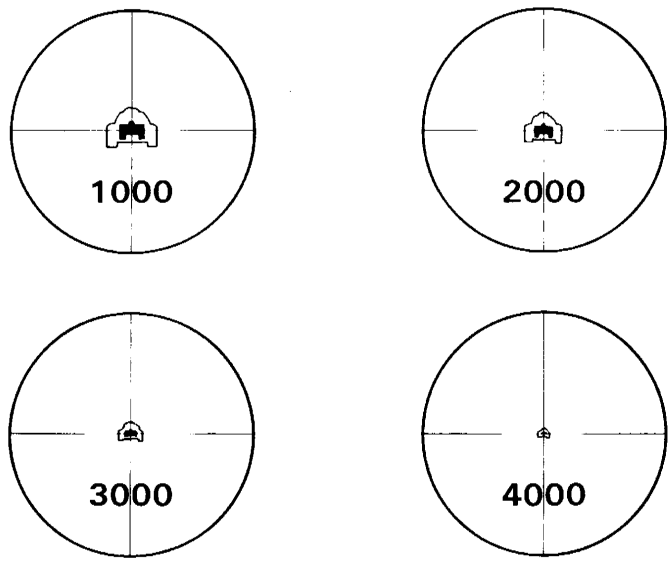

Fig. 3 -- Gunner's sight picture

types around the world there are numerous segments of terrain 200 m long or shorter.

Such a short dash time reduces exposure time, resulting in

- fewer shots fired
- more missile aborts
- more errors in gunner-lead fire control systems.

By stopping and accelerating across fairly short segments of terrain, Ninja will greatly reduce the number and accuracy of the shots taken at it. First of all, 17 seconds does not permit an enemy gunner much time to pick up the target as it comes into view, train his system on it, apply lead, and fire (or, in the case of a missile, track and fire). Second, by quickly disappearing from view, Ninja will force more missile aborts, even in top-level missile systems. And, third, Ninja's rapid acceleration should introduce an error source that can significantly reduce the probability of being hit.

We realize, of course, that a small, light vehicle such as Ninja will have inherent difficulty negotiating the complete spectrum of terrain and obstacles that a full-size tank can handle. Ameliorative measures to be explored in the Ninja research program include articulating the Ninja team/pair in difficult circumstances and, perhaps, using specialized low-ground-pressure designs.

LIFE CYCLE COST SAVINGS

Ninja offers significant savings in life cycle costs by dramatically reducing manpower needs. And this remains true even when accounting for maintenance support.

Although we have not examined organizational possibilities for Ninja in any detail, we currently envision the system operating in platoons of six and, within platoons, in pairs. The systems are paired so that the single crew member in each unit will not feel that he is alone on the battlefield; a "buddy system" also suggests the possibilities of arming the two units with different and complementary weapons suites and of mutually "covering" one another. The platoon of six units has eight crew members: the six drivers plus two maintenance/driver alternates who move from unit to unit as needed. A comparable platoon of six four-man systems (using crew maintenance) requires three times as many personnel.

III. RESEARCH AREAS

Realizing the potential of the Ninja concept requires advances in several technology areas, as Figure 4 suggests. The areas circled in bold will require starting new projects; in the remaining areas we anticipate that the Ninja will be able to borrow from other programs. For instance, we do not envision inventing new armor for Ninja. Instead, we plan to capitalize on current armor work. Similarly, we hope to adapt communication and navigation technology from other ongoing efforts, such as those of the Naval Ocean Systems Center in San Diego, the U.S. Army Tank-Automotive Command, and the DARPA/Defense Sciences Office.

Figure 5 displays the technological developments required in the four technology areas now of chief interest to the Ninja program: the sensor array, fire control, the weapons suite, and the man-aided robotic station itself.

Sensor array. We believe that an integrated IR/radar sensor array may be the best approach. We also envision it coupled to the navigation sensors. Whatever approach is finally adopted, it must be able to

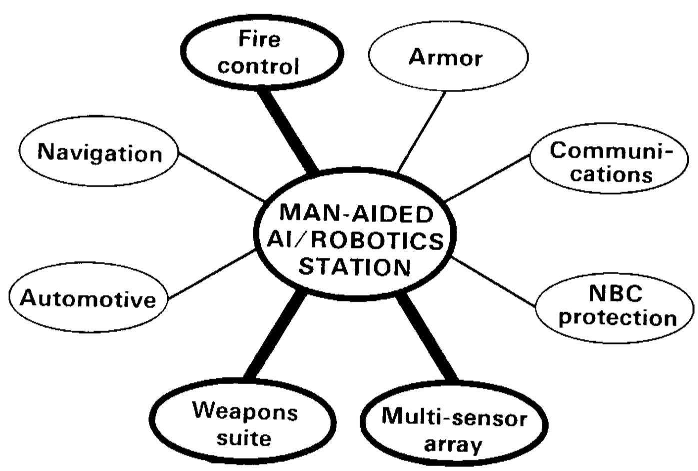

Fig. 4 -- Technology areas

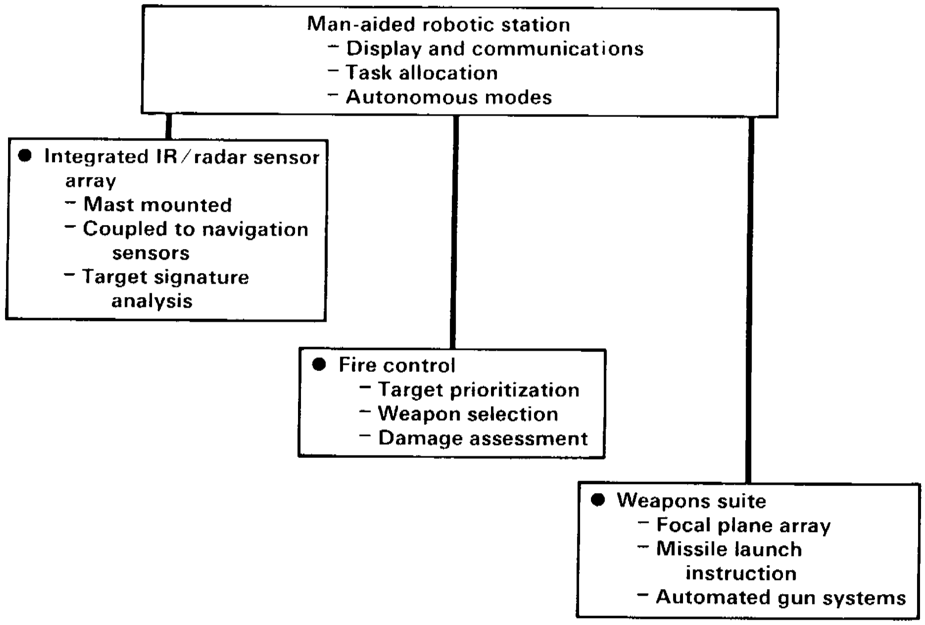

Fig. 5 -- Required technology developments

acquire and track just as well as personnel do in the current system. A mast-mounted sensor array will permit Ninja to see without being seen and also to fire its missile from defilade positions. Such a system would be suitable for light division, RDJTF, and contingency missions against a large array of tactical targets.

We believe that the sensor array will permit target signature analysis and some capability for IFF. It may ultimately identify targets even better than can personnel.

Fire control. Fire control is a complex process: scanning the terrain, acquiring a group of targets, putting together a prioritization list from which the operator can select, selecting which weapon to engage the highest priority target with, laying on, applying lead in the case of a gun, tracking in the case of a missile, firing the system throughout the engagement, and assessing damage. Ultimately we envision the machine doing all of this. Where it fails, the man can intercede. But each time he does so marks an area in which we are short of our goal.

Weapons suite. We described and justified the proposed weapons suite in a preceding section. If Ninja is to achieve the proposed firepower, we need to see advances in several weapons-related technology areas. Ninja will require advanced, multi-spectral focal-plane array sensors for target acquisition and tracking. To ensure tactical flexibility and responsiveness, the system will need missiles that are field-configurable via break-on-launch umbilical cables. Ultimately the Ninja weapons suite will demand a very high order of automation to free the single crew member from all but command-level tasks and decisions. The automation of this suite is a major area of work.

Man-aided robotic station. Task allocation may be the most important aspect of design here. The operator and the robotic station are constantly communicating with each other, and as they do so the operator constantly releases levels of autonomy to the machine. For instance, at a certain time the machine may be totally responsible for target acquisition and engagement, but it may not be allowed to fire without the man's permission. At another time, though, the man may allow the machine even this decision. Conversely, the machine may indicate to the man that he must take over a certain function, e.g., navigating in especially treacherous terrain, or identifying an unexpected type of target, which has become--at least temporarily--too difficult for it to handle.

Clearly, artificial intelligence (AI) will play a central role in the man-aided robotics station. A detailed digression into AI is inappropriate here; however, the area of expert systems--the most highly developed of the disciplines within AI--is expected to be a rich source of architectures and techniques for Ninja robotics. Reliance on strict logical/functional design approaches for the man-aided robotics station will not be adequate, for Ninja must be capable of carrying out a variety of complex, interrelated tasks that have classically been the province of humans. AI research has shown these kinds of tasks to be most amenable to automation via heuristic, rule-based approaches--expert systems.

Table 3 indicates how we envision the man-aided robotics station taking over crew functions. As we develop each of these systems, we can test its capability by comparing its performance to that of a manned system in the same scenario.

Target acquisition. We expect to develop a system that can acquire targets and make up a target list just as well as two crew members and a forward-looking infrared (FLIR) sensor.

Target engagement and driving. We anticipate that target engagement and driving will be the two functions which the crew member will most often wish to assume himself. In these two areas, and possibly in others, the capability for the man to intercede should be preserved.

Command and Control. As much as possible Ninja will handle communications automatically. For instance, the machine should be able to report its location and operations without the crew member interceding.

Table 3

CREW FUNCTION ANALYSIS

Major Crew Functions	Man-Aided Robotics Station
Target acquisition	• Sensor array performance greater than or equal to two men + FLIR
Target engagement	• Permission to fire • Man intercession
Route selection and driving	• Man intercession
Command and Control	• Automatic communications • Man intercession for change orders
Security	• Automated sentry and outposts
Maintenance	• TMDE (3rd generation) • Maintenance support team

Security. We do not want to tie the security system to the sole crew member. We envision a system that is its own automated sentry. It should be able to observe from its base position and even send out remote sensors of some sort. Since it never grows tired, such a system might well provide better security than a crew.

Maintenance. We described above the possibility of using a two-man maintenance support team to support a platoon of Ninja units. We envision a system that has at least third-generation test, maintenance, and diagnostic equipment--equipment that constantly checks itself and reports current status. Using trend and cumulative damage monitoring algorithms, it will report on systems as they age and deteriorate, and not just when they fail.

IV. THE NINJA PROGRAM

We are continuing to evolve the Ninja concept, consulting with users at the U.S. Army Armor Center (Ft. Knox) and elsewhere to determine specific operational goals. We want to improve the performance specifications so that we can provide direction to industry.

We are putting together a detailed TTO program which we would like to be as precise as possible so that we can coordinate what will be a large number of widely separated efforts.

The initial schedule for the proposed DARPA/TTO Ninja program begins with a concept/program definition effort early in fiscal year 1985. This effort will focus on system concepts, and technical and program analyses, and will draw on Service user commands for initial operational concepts. It will continue throughout FY85, and into early FY86.

By the second or third quarter of fiscal year 1985, we hope to begin a series of industry design studies, extending over two to three years and probably competitive, in the areas of prime concentration reviewed above: the man-aided robotic station, the IR/radar sensor suite for fire control, and the automated weapons suite. At the same time we hope to capitalize on other ongoing research in such areas as computer-aided navigation (DARPA/Defense Sciences Office) and the U.S. Army Tank-Automotive Command chassis testbed program. We anticipate the active involvement of Service R&D commands throughout the program, especially in the development of experiments and the design of testbeds.

The Ninja project is currently funded for all of fiscal 1985. Its future rests on how well it succeeds in its opening phases.

Appendix

OTHER LIGHT VEHICLE CONCEPTS

Several current projects resemble Ninja to some degree, most notably the Light Armored Vehicle (LAV), the Mobile Protected Gun System (MPGS), and the U.S. Army's remotely-manned robotic vehicle.

Unlike Ninja, the Light Armored Vehicle is a lightweight personnel carrier type of system. It provides a large, enclosed armored volume with limited occupant protection and a relatively insignificant weapons suite. This is an ongoing Marines Corps program from which the Army has recently withdrawn.

Another system on the drawing board, the Mobile Protected Gun System, has been through several iterations. The MPGS program originated in the armored combat vehicle technology program. At one time the system was planned to weigh 19 tons with a 75 mm automatic cannon. Currently plans are moving toward a 19 to 21 ton system with a 105 mm cannon.

The U.S. Army Tank-Automotive Command may develop a robotic vehicle of some kind in addition to the mine-clearing system "Robat." The crew would perform their functions from a remote van. Although such a system removes the crew from the vehicle, it relocates them rather than reduces their number. Such remotely manned systems are not autonomous since the system is not taking over the crew's functions.

Compared to these systems, Ninja is a radical innovation. The other systems do not use automation to reduce the size of the crew. (An exception is the use of an automatic loaded gun system which may eliminate one man from the system.) Thus, each of these systems retains the conventional three- to four-man crew. The chief goal of the Ninja concept, by contrast, is to reduce the crew while retaining--and perhaps increasing--the capabilities of the system. The eventual goal is an unmanned, fully-automated, autonomous system. For the foreseeable future, however, the system will require a crew of one who can take over functions such as target acquisition, engagement, and navigation when the automated subsystem needs help.

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